# CLIMATIC TEMPERATURE NORMALS

Nathaniel B. Guttman and Marc S. Plantico
National Climatic Data Center
Asheville, North Carolina 28801

## I. INTRODUCTION

The National Climatic Data Center has the responsibility to fulfill the mandate of Congress "...to establish and record the climatic conditions of the United States" (15 U.S.C. 313). The World Meteorological Organization (WMO) recommends that member countries should compute normals for representative stations. Normals are defined as "period averages computed for a uniform and relatively long period comprising at least three consecutive ten-year periods" (WMO, 1979).

Combining the WMO recommendations with the Congressional mandate, the National Climatic Data Center prepares daily normals of maximum and minimum temperatures. Daily normals are not explicitly treated in the WMO regulations, but period averages are defined as the "arithmetical mean of climatological data..." (WMO, 1979).

The published 1951-80 daily normals of maximum and minimum temperatures were prepared by interpolating between average monthly values. The interpolation scheme was a cubic spline fit following the procedures described by Greville (1967). The series of daily values resulting from the cubic spline yields a smooth curve throughout the year that represents the annual temperature cycle for a station. Each series was edited to remove spurious inflection points caused by rounding and to ensure functional relationships and consistencies among the several variables for which normals were prepared.

These published normals are synthetic in the sense that they are interpolated from monthly values. The WMO (1983) discusses synthesized data from the viewpoint of data reconstruction and estimation of missing values, but not from the viewpoint of substitution for available data. Of importance, however, is the WMO guideline that synthesizing be based on sound physical reasoning and indicate the probable error involved. This paper examines the errors in the synthetic, published normals.

In order to examine the error, thirty-year averages of serially complete daily maximum and minimum temperatures observed at 74 National Weather Service first-order stations from 1951-80 in the eastern half of the United States were computed. Figure 1 shows the station locations. These averages were then arranged into series of 365 daily maximum and 365 daily minimum temperatures for each station and are called 30-year average daily temperatures. The station network contains stations that did not experience significant moves during the 30-year period.

This study compares the published normal and 30-year average daily temperatures with the purpose of determining how well the published normals describe the daily temperature climate. If significant departures are found, they should be identified and described since energy users and planners, farmers and others could be impacted. If the published normals present an adequate description, then the cubic spline interpolation through mean monthly values is a cost-effective procedure for computing normals. The cost effectiveness results from reduced processing when working with 12 monthly values instead of 365 daily values.

## 2. COMPARATIVE ANALYSIS

The initial hypothesis in the analysis was that if the annual series of normals and 30-year average daily values represent nearly the same curve, then the series of differences between the two curves should be random and uncorrelated. The difference series of both maximum and minimum temperatures were subjected to linear trend, runs up and down, runs above and below the mean, and serial correlation tests. The tests were performed using the STATLIB computer package (Tryon and Donaldson, 1978) and are described in the OMNITAB User's Guide (Ku, 1973) with further description given by Hald (1952) and Brownlee (1960).

The hypothesis was rejected at the .05 confidence level for all stations for both maximum and minimum temperatures. Test results indicated highly significant non-randomness from the runs tests and a highly significant serial correlation. Linear trends were not apparent at any station. Selected time plots of the annual difference series indicated that the non-randomness could possibly be attributed to mixing of different seasonal synoptic environments. Note in Figure 2, for example, the greater variation in the 30-year average daily temperature series during the winter season compared to the summer season.

The tests were repeated on seasonal (January through March, ..., October through December) difference series. Similar results were

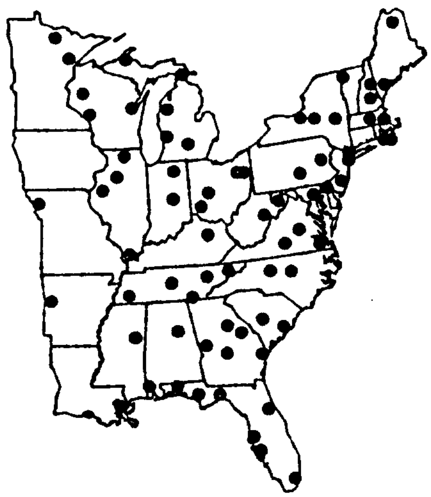

*Figure 1. Station locator map.*

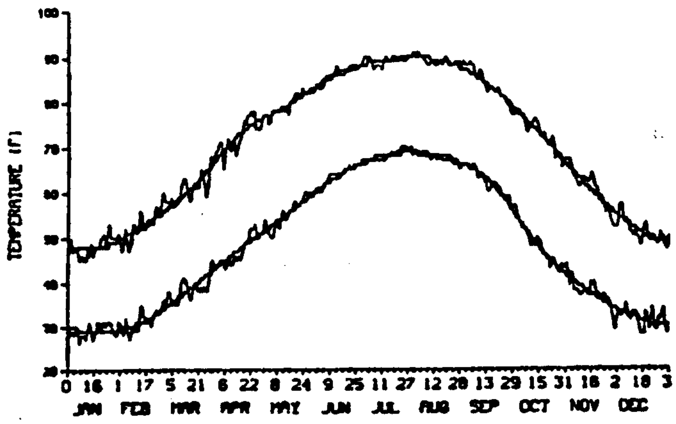


*Figure 2. Annual time series of Chattanooga, TN spline fit and 30-year average daily maximum (top curves) and minimum (bottom curves) temperatures.*

obtained, all stations failed but the magnitude of the test statistics was generally reduced by half. Knowing that the serial correlation could influence the runs tests, the seasonal series were modeled by a first order auto-regressive process using the BMDP time series computer package (1981). Examination of autocorrelation and partial autocorrelation functions (Figure 3, for example) justified the model in a statistical sense. Physically, a one day persistence or lag in the 30-year average daily temperatures was considered reasonable in terms of the instability of temperature distributions as discussed by AFCRL (1967; 1968, a-d). It was also considered reasonable in terms of multi-day persistence that is common in the daily weather associated with the passage of pressure centers over a station.

Residuals (original difference series minus modelled series) from the first order autoregressive model were passed through the STATLIB randomness tests. Results indicated that the serial correlation was removed from the seasonal maximum and minimum temperature difference series by the model. The runs tests, however, showed non-randomness in the seasonal series at many more stations than could be expected by chance. In all cases, fewer runs were observed than expected. Table 1 summarizes the tests results.

The areal extent of non-randomness in the residual series was mapped by season to try to isolate geographical similarities. Unfortunately, no clear-cut pattern emerged. In the first quarter (January through March) non-randomness in the maximum temperatures prevailed in the Southeast from Maryland to Florida. Randomness appeared to prevail from the Alabama Gulf Coast northeastward along the Appalachians into New England and also in the Great Lakes area. The minimum temperatures exhibited randomness in Pennsylvania and West Virginia as well as in Illinois, Wisconsin and Northern Michigan. The rest of the area was non-descript.

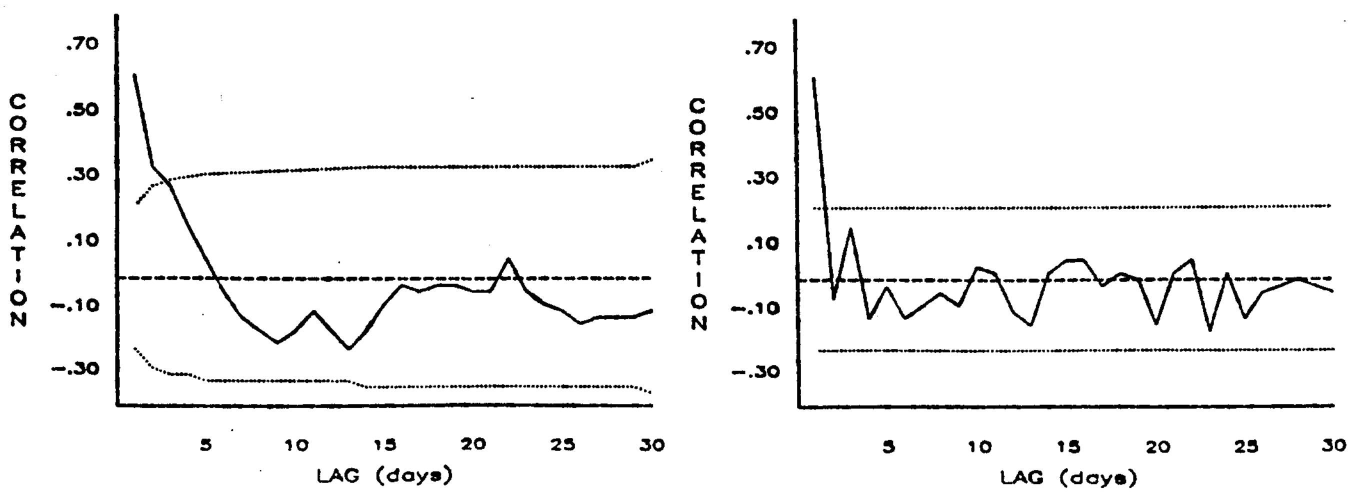


*Figure 3. Autocorrelation (a) and partial autocorrelation (b) for Green Bay, WI winter season maximum temperature differences. Dotted lines indicate .05 significance limits.*

| | Runs Up Max | Runs Down Min | Runs Above Mean Max | Runs Below Mean Min | Serial Correlation Max | Serial Correlation Min |
|---|---|---|---|---|---|---|
| **Jan-Mar** | | | | | | |
| Accept | 48 | 41 | 73 | 67 | 74 | 72 |
| Reject | 26 | 33 | 1 | 7 | 0 | 2 |
| **Apr-Jun** | | | | | | |
| Accept | 49 | 34 | 72 | 71 | 74 | 74 |
| Reject | 25 | 40 | 2 | 3 | 0 | 0 |
| **Jul-Sep** | | | | | | |
| Accept | 24 | 10 | 67 | 59 | 74 | 74 |
| Reject | 50 | 64 | 7 | 15 | 0 | 0 |
| **Oct-Dec** | | | | | | |
| Accept | 46 | 42 | 72 | 70 | 74 | 72 |
| Reject | 28 | 32 | 2 | 4 | 0 | 2 |

*Table 1. Test results for quarterly residual maximum and minimum temperature differences.*

The second quarter residual maximum temperature pattern was similar to that of the first quarter. The residual minimum temperature pattern showed randomness in the Tennessee and Ohio Valleys northward into Michigan and Wisconsin. The Southeast was consistently non-random. No consistency was evident from West Virginia northeastward through New England.

Residual maximum temperatures in the summer quarter did not exhibit any discernible geographical pattern of randomness except in the Gulf Coast, Florida and southern Georgia area. In this region, non-randomness prevailed. The residual summer minimum temperatures were non-random throughout the eastern half of the United States except for a few scattered stations in the northern states. Because of the small variability and persistent feature of summer temperatures at most locations, the residuals were often zero. The excellent fit of the model led to long runs in the residual series thereby causing the runs test hypothesis to be rejected.

Autumn maps did not exhibit any geographical consistencies in either the residual maximum or minimum temperatures.

Lacking geographical clues for the nature of the residual data, time series by quarter (Figure 4, for example) were examined for several stations. Obvious cycles and trends that may have caused the non-randomness were not apparent. However, a few interesting patterns emerged that warranted further investigation. A subjective analysis of the series revealed the possible existence of a January thaw, a cool period at the end of March, warming in April, late summer warming, and a November warming followed by cold temperatures.

These periods were then examined in more detail. The 30 values (1951-80) for a calendar date of maximum and minimum temperatures at all 74 stations were extracted from the data base for January 16 - February 4, March 12-30, April 12-30, August 26 - September 14 and November 10 - December 4. The departures of the temperatures from the published normals were computed, and the number of positive and negative departures for each date were tabulated.

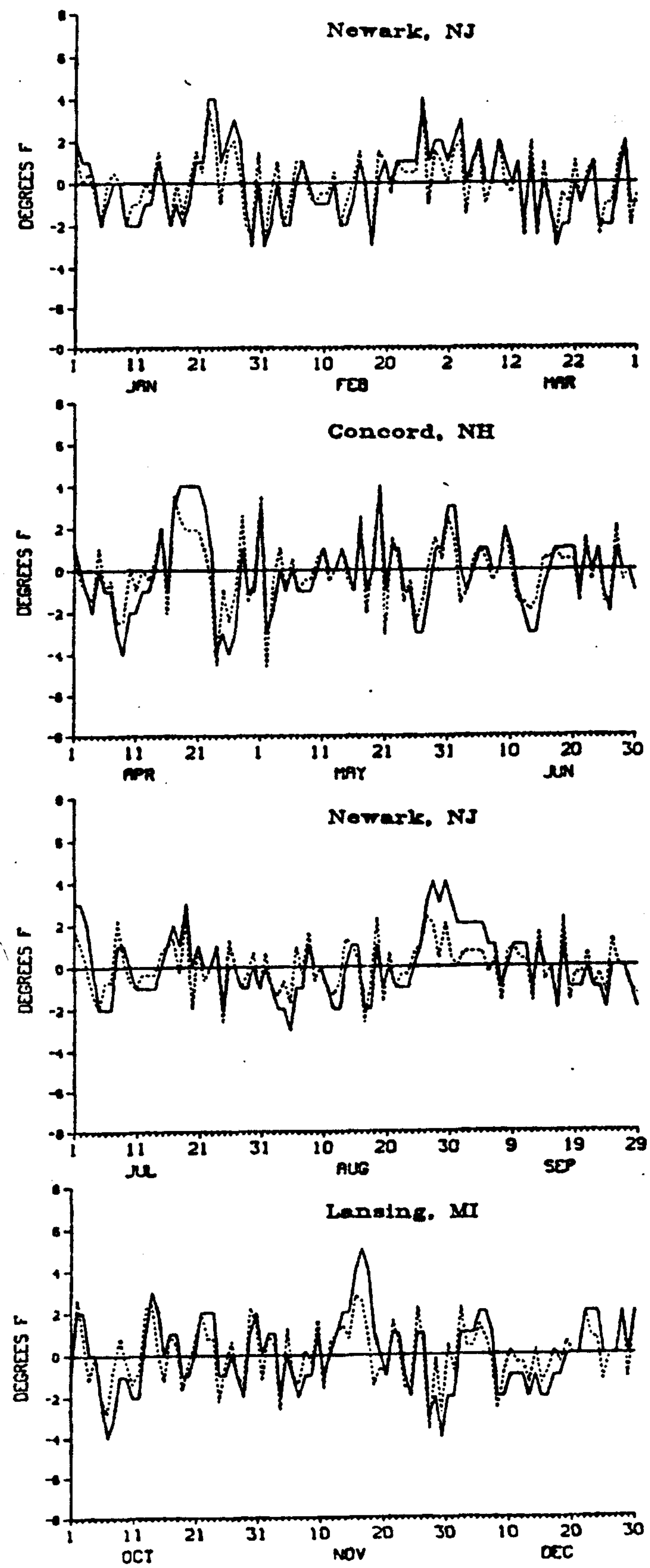


*Figure 4. Maximum temperature differences (solid curve) and residuals from persistence model (dotted curve).*

Hypothesizing that if the normals adequately represent the climate, the number of positive departures for a date should equal the number of negative departures, i.e., the median value of the departures should equal zero. Using a sign test described by van der Waerden (1969), the confidence limits for the median were determined. The departure distributions were then tested at the .05 confidence level for the null hypothesis that the observed medians were statistically equal to zero.

Significant positive departures of both the maximum and minimum temperatures occur in January in the northeast part of the study area. Figure 5 shows the significant dates of the minimum temperatures (the map for the maximum temperatures is essentially the same). What is commonly known as the January thaw appears to begin around January 20 in the Great Lakes states and then progresses southeastward in time. It also appears in New England around January 24. The duration of the above normal temperatures is about three to five days. Figure 6 shows that cold temperatures follow the January thaw. Part a) indicates a tendency for the northern states to have below normal minimum temperatures for two or three days at the end of January and beginning of February. During this same period, part b) shows that maximum temperatures are colder than normal along the mid-Atlantic Coast.

Figure 7 depicts the dates of significant below-normal maximum temperatures in March. Although not shown, the minimum temperatures show the same pattern. The northern areas indicate two periods of cold around March 15-17 and 24-26. The southern areas indicate one cold period around March 26-27. About one month later, warmer than normal temperatures are common south of New England and Michigan, as shown in Figure 8. The maximum temperature pattern in this figure is the same as the minimum temperature pattern (not shown).

Late summer warming of a magnitude of more than 3 degrees above normal occurs during the last week in August in the northern states. A week later the southern states appear to be warmer than normal, but the magnitude is only about 1-2 degrees. Figure 9 shows the minimum temperature pattern; maximum temperatures exhibit a similar pattern.

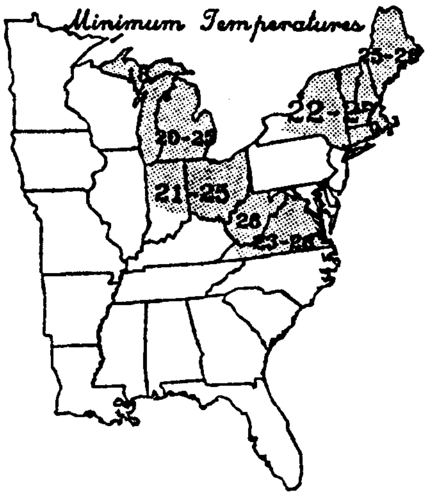


*Figure 5. Dates of significant January warming.*

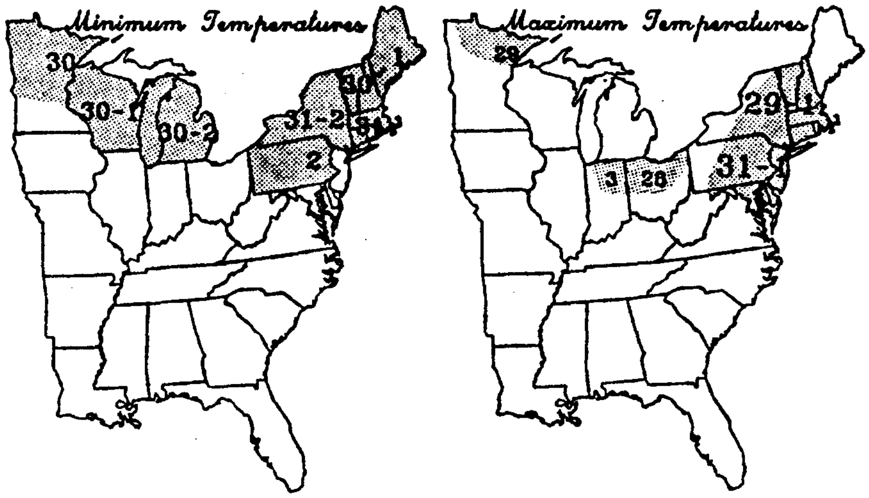


*Figure 6. Dates of significant January-February cooling.*

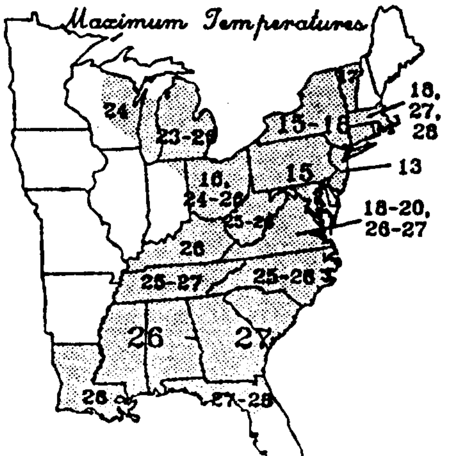


*Figure 7. Dates of significant March cooling.*

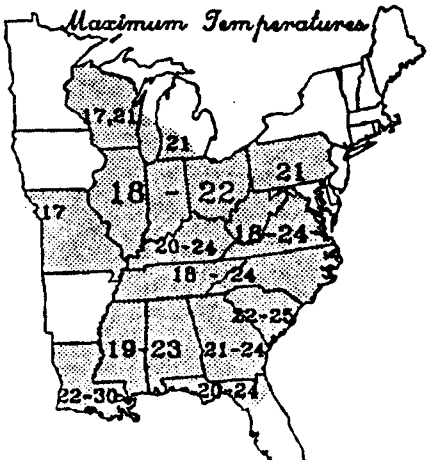


*Figure 8. Dates of significant April warming.*

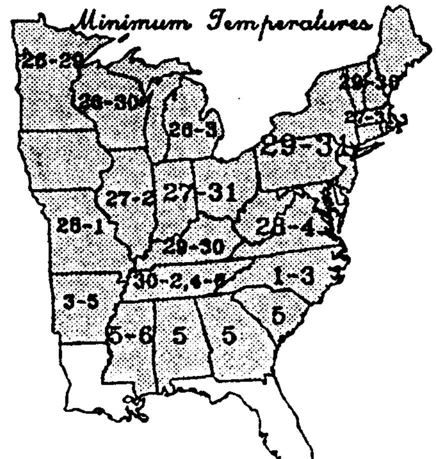


*Figure 9. Dates of significant August-September warming.*

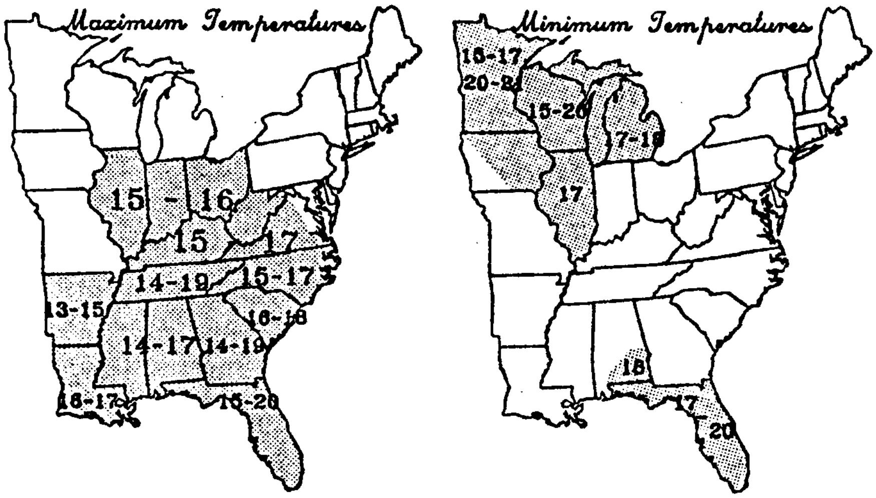


*Figure 10. Dates of significant November warming.*

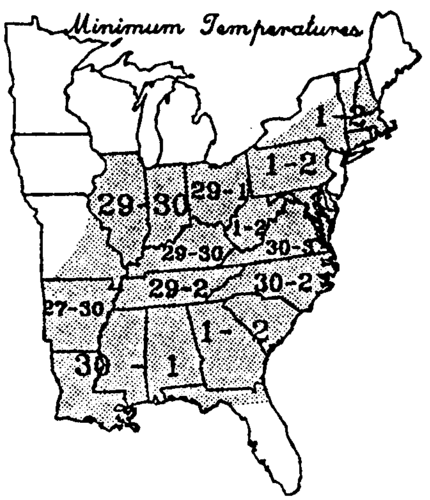


*Figure 11. Dates of significant November-December cooling.*

Maximum temperatures in the southern two-thirds of the study area are warmer than normal in mid-November (Figure 10a). Above normal minimum temperatures do not follow the same pattern. Two separate geographical areas (Figure 10b), the Great Lakes and Florida, experience mid-November above normal temperatures. At the end of the month, cold minimum temperatures prevail throughout the eastern U.S. from November 29-December 2 (Figure 11). Maximum temperatures (not shown) exhibit a similar pattern.

Whether the anomalies from the normals shown in Figures 5-11 are climatic singularities or failure of the spline fit to adequately represent seasonal transitions is speculative. Further research is necessary to describe the anomalous periods in terms of climatic patterns rather than in terms of departures from a mathematical interpolation procedure.

Acknowledging that the two sets of maximum and minimum temperatures are different, the question remains, how different are they? Maps were prepared of the range of differences by season and variable. Winter maximum temperature difference ranges are largest in the Tennessee Valley (12-13 degrees) and smallest in southern Florida (4-5 degrees). Secondary minima occur along the eastern shore of Lake Michigan (6 degrees) and in the Middle Atlantic - southern New England area (6-8 degrees). Secondary maxima occur in northern Ohio (11 degrees) and in northern Vermont and New Hampshire (10-11 degrees).

Winter minimum temperature difference ranges are largest along the northern New England coast (12 degrees), west of the Great Lakes (10-11 degrees), central Gulf Coast (10-11 degrees) and western Tennessee (10 degrees). The smallest ranges occur in southern Florida (6 degrees) and the Middle Atlantic area (6-8 degrees).

The spring maximum temperature range maps shows a north-south gradient of 8 to 3 degrees in the southern half of the study area. Relative minima occur in lower Michigan (7 degrees) and southern New England (5-6 degrees). Relative maxima occur in southern Indiana and north central New York (10 degrees). The minimum temperature range map shows the largest ranges occurring in the Ohio and Shenandoah Valleys (10 degrees) and in central New York eastward into New Hampshire (8 degrees). The smallest ranges are in southern Florida and Cape Code (4 degrees) and around Lake Superior (5-6 degrees).

Summer maximum temperature difference ranges gradually increase from 4 to 8 degrees northward from Florida. The smallest values are along the Florida Gulf Coast (2 degrees). The minimum temperature map depicts a north-south gradient in the inland areas from 10 to 4 degrees. The highest values are in lower Michigan, and a secondary maximum (6 degrees) occurs from northern Alabama into central South Carolina. The lowest values (3-4 degrees) occur along the Gulf and Atlantic Coasts.

The largest autumn maximum temperature difference ranges (10 degrees) occur in a V-shaped area from Minnesota southeastward to West Virginia southwestward to Arkansas. Another maximum of the same magnitude occurs in the eastern Carolinas. The lowest values occur in northern Michigan and eastern Pennsylvania through southern Vermont (6 degrees), and in southern Florida (4 degrees).

The autumn minimum temperature difference range map has maximal values in northern Minnesota - southeastern Wisconsin (10-13 degrees), Maine (10-11 degrees), West Virginia (10 degrees) and Mississippi-Alabama-central Tennessee (10-11 degrees). Southern Florida has the lowest values (6 degrees). Most of the study area shows ranges of 7-9 degrees.

For most stations in all seasons, the absolute value of the highest and lowest maximum or minimum temperature difference is half the range. There is very little skewness of the range around the mean of the seasonal temperature differences. The variability of the temperature

| | Jan - Mar | Apr - Jun | Jul - Sep | Oct - Dec |
|---|---|---|---|---|
| **Maximum Temperature** | | | | |
| Low | 1.0 (Florida) | 0.6 (Florida) | 0.6 (Florida) | 0.8 (Florida) |
| High | 2.2 (Ohio Valley), | 2.0 (Michigan) | 1.8 (Great Lakes) | 2.1 (Ohio Valley) |
| **Minimum Temperature** | | | | |
| Low | 1.4 (Florida) | 0.8 (Florida) | 0.7 (Florida) | 1.2 (Florida) |
| High | 2.4 (Wisconsin, New England) | 1.7 (Ohio Valley) | 1.9 (Michigan) | 2.0 (Ohio Valley) |

*Table 2. Standard deviations of temperature differences (°F).*

differences is seasonally and latitudinally dependent. The standard deviations are lowest in summer and highest in winter. They are also lowest in Florida and highest in the Ohio Valley-Great Lakes area. Table 2 summarizes the variability of the standard deviations.

## 3. CONCLUSIONS

Based on data from 74 stations in the eastern half of the U. S., the normals and 30-year average daily temperatures were determined to be different. The magnitude and variability of the differences, which are measures of the errors in the synthetic, published normals, are sufficient to question the use of the cubic spline fit through monthly values to describe a daily climate.

The investigation into the structure of the differences should be continued. It was determined from this study that one day persistence is a feature when working with 30 years of daily data. The residual series created after modelling the serial correlation still shows non-randomness for many stations. The causes should be identified and attributed to sound meteorological principles. The possibility of climatic singularities as evidenced from the analysis of the 30 temperatures (1951-80) on selected dates also needs to be investigated in more detail. Further study will lead to a better description of the temperature climate than is currently provided by the published normals.

## ACKNOWLEDGEMENTS

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